

Contingencies, Logic, and Learning

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A logical analysis of operant learning is presented. In total, the analysis makes a number of predictions that are different from the predictions of any other theory. Individual predictions can be explained by other theories, but the pattern of predictions is unique. Some tests of the predictions of the analysis with human newborns are described. The analysis predicts increased variance in sucking with the introduction of continuous reinforcement. This does occur. The analysis predicts a decreased rate of sucking with a shift from continuous to partial reinforcement. This does occur. The analysis predicts an increased rate of sucking with a shift from continuous reinforcement to continuous plus noncontingent reinforcement. Due to methodological deficiencies, we have been unable to test this prediction. However, it has been confirmed by others. The most exciting prediction of the analysis is a rapid way of producing extinction. That has not been tested with newborns; however, there is confirmatory evidence in the literature.

Key words: contingency, learning

This paper deals with operant learning in human newborns. We use a very simple technique to assess operant learning in these subjects. The infant sucks on a pacifier. The positive pressure suck is the operant. The pacifier is connected via a pressure transducer to a computer. The computer delivers reinforcement. The reinforcement is an audio-visual event, presentation of a bullseye along with a beep. The duration of the event is normally two tenths of a second. A variety of schedules can be programmed via the computer. With this simple setup, it is easy to demonstrate learning by newborns with any conventional measure of learning. Figure 1 shows cumulative records taken from an infant. The curve on the left shows sucking in baseline, with no reinforcement. The curve on the right shows what happens when reinforcement becomes contingent upon sucking. In essence, more sucking occurs as a consequence of reinforcement. This kind of change is typical of any organism.

There are some characteristics of change in newborns that have not previously been noted in other organisms. The most striking of these become ob-

vious if one looks at the distribution of intersuck intervals (ISI), or more generally, interresponse intervals (Figure 2). The most striking effect of reinforcement is an increase in the variance of ISI. The mean ISI usually decreases, but the variance always increases. In 11 of 15 newborns studied by Walton and Bower (1992), the addition of contingent reinforcement resulted in a lower mean ISI when compared to the mean ISI in baseline. However, for all 15 infants the addition of reinforcement resulted in increased variance of ISI compared to baseline variance (Figure 2). There is an increase in the frequency of short ISIs and an increase in the frequency of long ISIs. Although this kind of effect could be explained away as having no significance, it can also be explained in a way that has implications for infants and for the control of behavior in general.

The thinking outlined here was first applied to infants by Piaget (1936). An extended description was presented by Bower (1988), who at that time had no newborn learning data. It requires a logical analysis of contingency. Such analyses are mathematically simple, certainly much simpler than the analyses presented by Watson (1997). A logical analysis of operant learning begins with a very simple assumption that operant learning is based upon the

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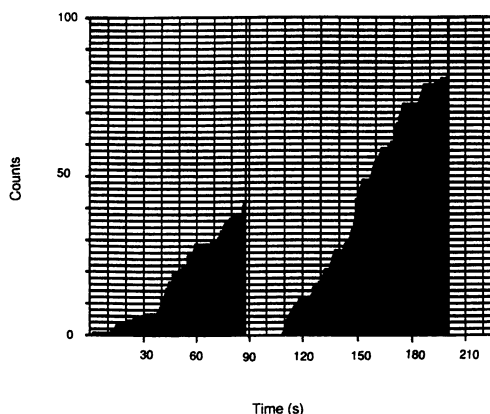


Figure 1. The curve on the left shows a cumulative response curve obtained during a non-reinforcement baseline. The curve on the right shows the cumulative responses of the same infant during continuous reinforcement (CRF).

organism's ability to detect relations between its actions and events in the world. Given an act and an outcome, there are four possible pairings. These are listed in Table 1. Operant learning typically begins with continuous rein-

TABLE 1

	Act	Outcome
Line 1	1	1
Line 2	0	0
Line 3	1	0
Line 4	0	1

Note. 1 indicates that the act or outcome occurs. 0 indicates that the act or outcome does not occur.

forcement. In continuous reinforcement, the organism is presented with Lines 1 and 2 of Table 1. Is there any way to summarize this pattern of co-occurrence? Logical notations do allow us to form such summaries. Using logical notation, we can summarize the relationship between act and outcome. Within the framework of a formal system of logic, such a relationship is valid or true under precisely defined conditions. If our summary reads ArO , where A is the act, O is the outcome, and r is the relationship, the summary

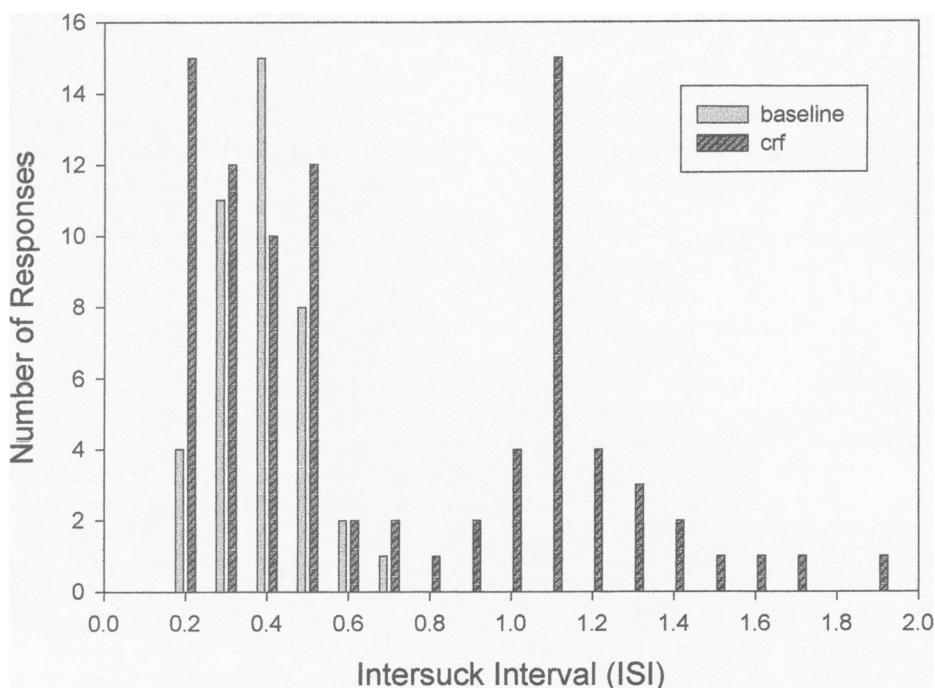


Figure 2. The distribution of intersuck intervals during a nonreinforcement baseline and CRF (black bars). As can be seen, variance increased during CRF.

is true whenever the term on the left of the relationship has a value less than or equal to the value on the right of the relationship (i.e., term on left \leq term on right). For an organism to decide that there is a relationship between *A* and *O* (act and outcome), the events that the organism encounters must satisfy the relationship

$$A \leq O. \quad (1)$$

The possible values to be entered into Equation 1 are given in Table 1. An organism on continuous reinforcement is presented with instances of Line 1 and Line 2. These two lines indicate that there is a relationship between *A* and *O*; however, they do not specify the relationship. In fact these lines are ambiguous between two possible relationships. The first possible relationship can be written in everyday language as "Whenever the act occurs, the outcome occurs":

$$A \rightarrow O. \quad (2)$$

The second possible relationship can be written as "If the act does not occur, the outcome does not occur":

$$-A \rightarrow -O. \quad (3)$$

The minus sign has the effect of reversing the values given in Table 1 so that 1 becomes 0 and 0 becomes 1. Checking Equations 2 and 3 against Equation 1, one can see that both of these relationships are valid or true in continuous reinforcement, when the organism is given only Lines 1 and 2.

It is my contention that human newborns treat these relationships as possible hypotheses and act to test the validity of these hypotheses. I make no apology for this terminology. If Krechevsky (1932) could write about hypothesis testing in rats, I can surely write about hypothesis testing in human infants. I would make clear, however, that I do not assume that a rat or a newborn has ongoing internal monologues in which it formulates hypotheses and works out ways to test them. I assume the whole process is more or less automatic, as automatic as the con-

veyance and divergence of our eyes in binocular vision. That said, I must also make it plain that I have no objection to any formulation that does posit internal monologues in some private language. It is just that, at present, I see no gain in such an assumption. The first point that I assert is that a newborn human on continuous reinforcement is unable to decide between the hypothesis embodied in Equation 2 and the hypothesis embodied in Equation 3. Given continuous reinforcement, both are valid. What should the infant do? I assert that the infant should search for an instance of Line 3 or Line 4. That is to say, the infant should respond at a high rate to test whether Line 3 ever occurs and at a low rate to check whether Line 4 ever occurs. Now that is exactly what happens when we put a newborn human on continuous reinforcement. There is an increase in the frequency of occurrence of short ISIs and an increase in the frequency of occurrence of long ISIs.

How can we test the utility of a logical analysis? The obvious first step is to manipulate outcomes as instances of Line 3 or Line 4 from Table 1. If we add Line 3 to Lines 1 and 2, we are shifting the organism from continuous reinforcement to partial reinforcement. Walton and I have done this by implementing a range of low variable-ratio (VR) schedules (Walton & Bower, 1992). A number of variable-interval (VI) schedules have also been studied (Meno, John, Armstrong, & Bower, 1997). What is the effect of Line 3 on an organism already familiar with Lines 1 and 2? Lines 1 and 2 together give the organism information that there is a relationship between act and outcome. However, they are ambiguous between Equation 2 and Equation 3. The addition of Line 3 instantly invalidates Equation 2. Equally instantly it validates Equation 3. To return to the hypothesis-testing framework, Line 3 instantiates Equation 3 ($-A \rightarrow -O$). In everyday language, Line 3 instantiates the hypothesis "If I do not suck, no bullseye and beep will occur." Let us

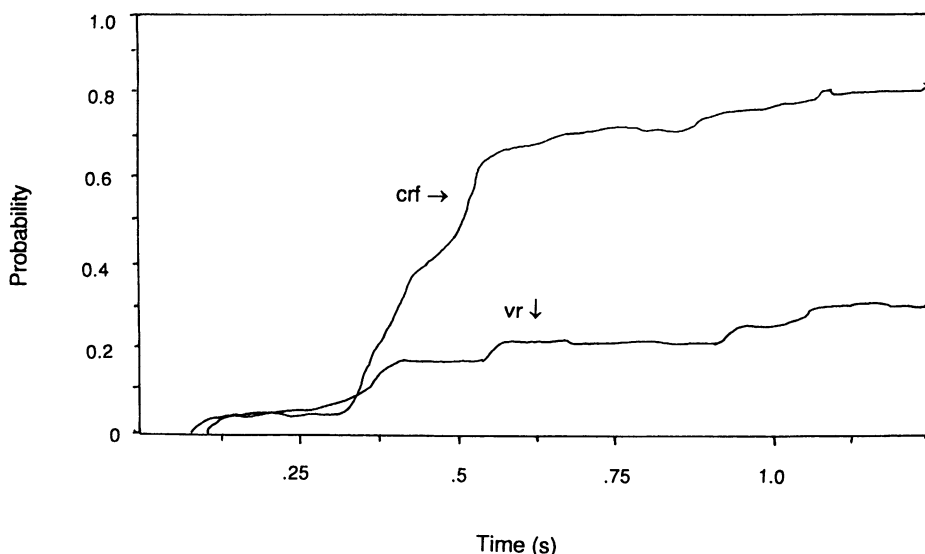


Figure 3. The conditional probability of a second suck given a first suck as a function of time in CRF and VR reinforcement schedules. The VR schedule produced a pronounced slowing of sucking.

continue on with this hypothesis-testing model. It can be argued that the biologically sensible thing to do with a new hypothesis is to test it, to become certain of its validity, before adding it to one's store of knowledge to be used whenever circumstances demand. How then would the newborn test this new hypothesis, $-A \rightarrow -O$? The obvious test is to withhold sucks, to test whether reinforcement ever occurs without a preceding suck. It would seem that this is exactly what the newborn does. Figure 3 presents the conditional probability of a second suck, given the occurrence of a first suck, as a function of time. Alternatively, the curves can be viewed as showing the cumulative proportion of ISIs as a function of duration of ISI. The figures show curves derived from different conditions of reinforcement. Figure 3 shows an extreme case. In all 18 of the newborns we have tested, the shift to partial reinforcement shifts the pattern of ISIs upwards in time. Short ISIs become rare, and longer ISIs become more common. Although again this pattern can be explained away, it can also be seen as the nontrivial outcome of a

nontrivial process, the logical analysis of contingent events.

Above, it was pointed out that only one instance of Line 3 is necessary to invalidate Equation 2 and validate Equation 3. Is newborn learning as rapid as that? The universal newborn response to the first occurrence of Line 3 is a prolonged pause in sucking. This pause could reflect surprise or startle. However, the same prolonged pause occurs after the next reinforcement in the majority of infants ($p = .00348$), indicating that the predicted shift in responding can occur very rapidly, even if not universally.

It should be pointed out that an identical pattern of change was obtained by Hillman and Bruner (1972) using a nutritive reinforcer with 6- to 8-week-old infants. A shift from continuous reinforcement to partial reinforcement produced increased pausing between sucks, exactly as the logical model predicts. Although it may seem a stretch, it should be pointed out that the phenomenon described here is similar to the so-called postreinforcement pause that occurs with fixed-ratio (FR), VR, fixed-interval (FI), and VI schedules

(Mazur, 1983; Skinner, 1938). Skinner proposed that pausing in VI is the result of reinforcement. If that were the only explanation, pausing would increase with exposure to the schedule. That is not the case with newborn humans; the pausing begins with or soon after the first nonreinforced act.

What happens if we add Line 4 to Lines 1 and 2 of Table 1 rather than adding Line 3? If, instead of shifting our infant from continuous to partial reinforcement, we add noncontingent reinforcement (NCR) to continuous reinforcement, what should ensue? In terms of the logical analysis, the addition of Line 4 instantly disambiguates the information provided by Lines 1 and 2. The occurrence of Line 4 instantly invalidates the hypothesis embodied in Equation 3 ($-A \rightarrow -O$). If the values of Line 4 are entered into Equation 3, we obtain $1 \rightarrow 0$; because one is greater than zero, the value on the left is greater than the value on the right. Clearly this runs afoul of the core Equation 1. An organism operating on logical principles would thus conclude that the hypothesis embodied in Equation 3 is invalid.

The addition of Line 4 to Lines 1 and 2, the addition of NCR to continuous reinforcement, provides validation of Equation 2 ($A \rightarrow O$). In everyday language in our experimental situation, the event validates the hypothesis "Whenever I suck, the bullseye and beep occur." How should our newborn go about testing this hypothesis? To test the hypothesis $A \rightarrow O$, the newborn should suck as fast as possible in order to discover if it ever happens that a suck occurs without a consequent reinforcement. The addition of NCR should produce an increase in the frequency of short ISIs. We tried to test this. Before trying, we knew that just this phenomenon did occur. When NCR is introduced, newborns do increase their rate of sucking. Semb and Lipsitt (1968) demonstrated this using a nonnutritive reinforcer. Unfortunately for us, our technique was fatally flawed and we never succeeded in studying

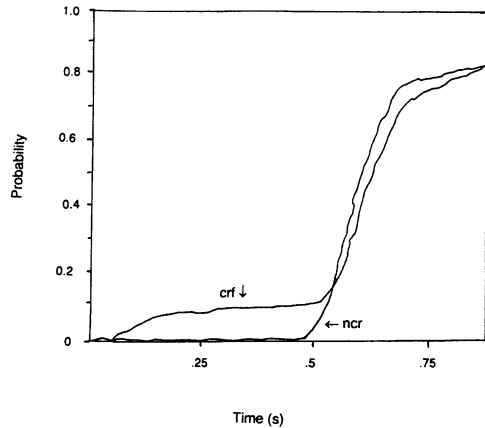


Figure 4. The conditional probability of sucking by an infant during CRF and CRF with NCR. NCR produced suppression of sucking for intervals less than 0.5 s.

the reactions of newborns to the introduction of NCR in our nonnutritive sucking situation. The reasons for our failure cast an interesting light on the abilities of newborns and so are worth reporting. The fatal flaw in our attempt, a flaw pointed out by Watson at the meeting where these results were presented, was that our NCR was not truly noncontingent. Rather it was contingent upon a nonresponse, not sucking. The program for NCR was set up in the following way. Continuous reinforcement was still available. Thus the infant would suck and obtain reinforcement. 0.5 s after that suck, if no suck had occurred or been initiated, the computer would deliver NCR with a probability of .25, .5, or .75 (varying among subjects). Regardless of probability, the subjects very rapidly picked up on the availability of "free" reinforcement. The results are shown in Figure 4. The typical newborn suppressed responding for 0.5 s, in essence waiting for the NCR, and initiated sucking only after the occurrence or nonoccurrence of the NCR. The suppression of ISIs < 0.5 s can be clearly seen in Figure 4, in which behavior with NCR is plotted along with the behavior of the same infant under continuous reinforcement alone.

This pattern of behavior seems to in-

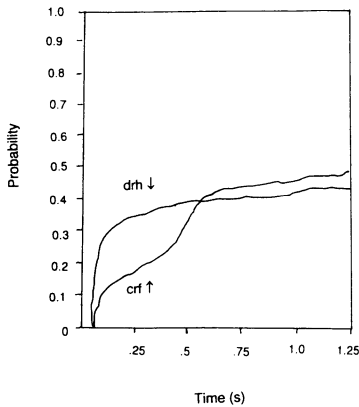


Figure 5. The conditional probability of sucking under two schedules, CRF and a DRH schedule in which responses were reinforced only if they occurred less than 0.5 s after a preceding suck. As can be seen, the infant did adjust to a schedule.

dicating a surprising sensitivity to time plus an ability to time behavior. We tested the flip side of this by shifting a few infants from continuous reinforcement to a schedule in which reinforcement was delivered only after the second of any pair of responses and then only if the ISI was less than 0.5 s (a differential reinforcement of high rates schedule). As Figure 5 shows, the newborns rapidly began to make the requisite adjustments to this sucking pattern.

Recently, we have succeeded in implementing a working NCR paradigm. We do not want it simply to test the effects of NCR. We are quite happy to accept Semb and Lipsitt's (1968) data as confirming the predictions of the logical analysis. However, unless we have a way of delivering NCR (Line 4 of Table 1), we cannot test the most exciting prediction of logical analysis for ourselves. That prediction is in essence a prediction of how to induce very rapid extinction. Suppose we begin an organism with continuous reinforcement and continue for some time. Suppose we then shift the organism to partial reinforcement and continue for some time. At the end of this, by conventional wisdom, we have an operant that is very resistant to extinction. But,

is it? Let us look at Table 1. What we have done with this schedule is expose our organism to numerous instances of Lines 1, 2, and 3. We have provided our organism with lots of evidence that Equation 3 is valid. On a logical analysis, what should happen if we present the organism with one or more instances of Line 4? Line 4 instantly invalidates Equation 3. Substituting the values from Table 1, we find that Line 4 leaves Equation 3 reading $1 \rightarrow 0$, which, of course, runs afoul of Equation 1, thus invalidating Equation 3. The result, of course, should be instant extinction. We have not been able to test this with human newborns. Walton has found that 8-month-old infants stop responding under those circumstances. Using a similar sequence, Monnier (1981) found not only extinction but also expression of anger and active withdrawal from the situation. Most definitively, Hammond (1980) presented rats with just this sequence, continuous reinforcement (Lines 1 and 2 of Table 1), partial reinforcement (Line 3 of Table 1), and finally NCR (Line 4 of Table 1). The effect of Line 4 was to extinguish the operant, dropping it back to baseline almost at once. As far as I know, the logical analysis is the only analysis that predicts this powerful effect, an effect that should greatly enhance the possibilities of behavior control.

In the study in question, newborns were given 5 min of continuous reinforcement in which a suck was reinforced by presentation of a female voice uttering a monosyllable. After that 5 min was up, half of the 16 newborns went into straightforward extinction in which sucking had no consequence. The other half were given a schedule that was designed to present them with information that there was no relationship between act (sucking) and outcome (female voice). In that schedule, reinforcement was presented on a VI schedule. NCR was also presented on a VI schedule. The schedule was set up so that on average a newborn would hear 75 contingent rein-

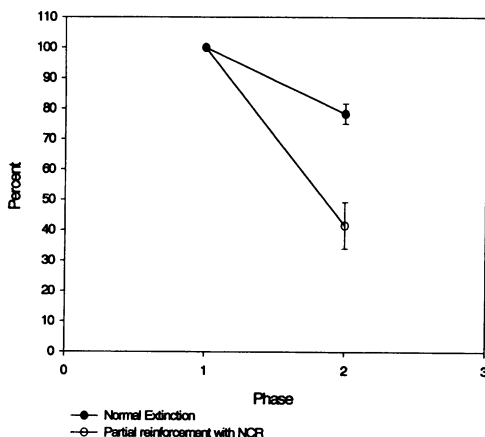


Figure 6. The decrement in responding between Phase 1 (CRF) and Phase 2 (normal extinction or mixed NCR and partial reinforcement).

forcements and 75 instances of NCR. The total number of sucks that occurred during the second phase was compared with the total number of sucks that occurred during continuous reinforcement. In terms of the logical analysis, the extinction procedure presents the newborn with an instance of Line 3 of Table 1, thereby confirming Equation 3. In extinction, therefore, we would expect responding to slow enough for hypothesis testing but no more. The other procedure, mixed partial and NCR, presents the newborn with examples of all four lines of Table 1, evidence that there is no relationship between act and outcome. The logical model predicts that this condition should result in a significantly greater decrement in responding than simple extinction. As Figure 6 shows, that did indeed occur.

I am aware that some psychologists, most notably J. S. Watson, have mixed all four lines of Table 1 without producing instant extinction in infants. I have a suggestion about how that may come about. We know that presentation of Lines 1, 2, 3, and 4 will not lead to instant extinction in rats if we present cuing stimuli that signal when Line 3 will occur and when Line 4 will occur (Hammond & Weinberg, 1984). I propose that any organism with a history

of making such discriminations will look for discriminative possibilities until the possibilities for search have been exhausted. Only then will extinction occur. If the situation is such that there are no discriminative possibilities, extinction should be rapid. If the organism has no history of such discriminations, like the rats in Hammond (1980), extinction should be rapid, as it presumably would be in a longer experiment with newborns.

The extinction of undesirable behaviors occupies a great deal of the time of clinicians who work with children. The procedure used above, inspired by the work of Hammond (1980), could possibly be another tool. There is a rational basis for the effectiveness of this procedure. Bower (1988) argued, on the basis of observation rather than experimentation, that many parents use this kind of mixed partial and noncontingent reinforcement to eliminate infant fussing when being put to bed. The possible uses for this paradigm are not restricted to that very common problem.

At present, there is a reawakened interest in theory building and hypothesis testing as core processes in child development (Gopnik & Meltzoff, 1997). Operant learning experiments provide the most precise and easily measured way of looking at hypothesis testing and changes in hypothesis testing with age. The core of this paper is presented in Table 1, which lays out all of the possible relations between an act and an outcome. Most psychologists focus on Line 1, and some incorporate Lines 1 and 2. The approach outlined in this paper asserts that all four lines must be taken into account. In the context of developmental psychology, this implies that we assume that our organism is thinking about possibilities, about what might be rather than only about what has happened. This line of thinking is more associated with psychoanalysis than with behavior analysis. Inasmuch as it adds a new dimension to our thinking about the development of young humans and new

tools for analyzing such fuzzy concepts as *theory building* and *hypothesis testing*, the fusion will be fruitful.

REFERENCES

- Bower, T. G. R. (1988). *The rational infant*. New York: Freeman.
- Gopnik, A., & Meltzoff, A. M. (1997). *Words, thoughts and theories*. Cambridge, MA: MIT Press.
- Hammond, L. J. (1980). The effect of contingency upon the appetitive conditioning of free operant behavior. *Journal of the Experimental Analysis of Behavior*, 34, 297-304.
- Hammond, L. J., & Weinberg, M. C. (1984). Signaling unearned reinforcers removes the suppression produced by zero correlation in an operant paradigm. *Animal Learning & Behavior*, 12, 371-377.
- Hillman, D., & Bruner, J. S. (1972). Infant sucking in response to variations in schedules of feeding reinforcement. *Journal of Experimental Child Psychology*, 13, 240-247.
- Krechevsky, I. (1932). "Hypotheses" in rats. *Psychological Review*, 39, 516-532.
- Mazur, J. E. (1983). Steady-state performance on fixed-, mixed- and random-ratio schedules. *Journal of the Experimental Analysis of Behavior*, 39, 293-307.
- Meno, K., John, N., Armstrong, E. S., & Bower, T. G. R. (1997). *Logical relations and operant responding*. Manuscript in preparation.
- Monnier, C. (1981). *La genese de l'exploration chez le bebe*. Lausanne: Presses Universitaires Lausanne.
- Piaget, J. (1936). *The origins of intelligence*. New York: Norton.
- Semb, G., & Lipsitt, L. P. (1968). The effects of acoustic stimulation on cessation and imitation of non-nutritive sucking in neonates. *Journal of Experimental Child Psychology*, 6, 585-597.
- Skinner, B. F. (1938). *The behavior of organisms*. New York: Appleton-Century-Crofts.
- Walton, G. E., & Bower, T. G. R. (1992, May). *Operant control of the single suck in newborns*. Paper presented at the meeting of the International Conference on Infant Studies, Miami, FL.
- Watson, J. S. (1997). Contingency and its two indices within conditional probability analysis. *The Behavior Analyst*, 20, 129-140.